



US009312995B2

(12) **United States Patent**  
**Baligh et al.**

(10) **Patent No.:** **US 9,312,995 B2**  
(45) **Date of Patent:** **Apr. 12, 2016**

(54) **SYSTEM AND METHOD FOR ADAPTIVE  
DOWNLINK COMP MODE SELECTION  
BASED ON UNIFIED CSI FEEDBACK**

(58) **Field of Classification Search**  
None  
See application file for complete search history.

(71) Applicant: **Huawei Technologies Co., Inc.,**  
Shenzhen (CN)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0002406 A1 1/2011 Ming et al.  
2011/0103287 A1 5/2011 Ma et al.  
2012/0218962 A1\* 8/2012 Kishiyama et al. .... 370/329  
2013/0310098 A1\* 11/2013 Baligh et al. .... 455/509

OTHER PUBLICATIONS

3GPP, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA):  
Physical channels and modulation (3GPP TS 36.211 version 8.7.0  
Release 8), ETSI TS 136.211 V8.7.0 (Jun. 2009) Technical Specifi-  
cation, 87 pages.  
Communication of priority received in Application No. 13790713.5-  
1559, mailed Jan. 21, 2015, 1 page.  
Extended European Search Report received in Application No.  
13790713.5-1851, mailed Apr. 29, 2015, 6 pages.  
Alcatel-Lucent Shanghai Bell, "CQI Definition for CoMP," 3GPP  
TSG RAN WG1 Meeting #69, R1-122479, Prague, Czech Republic,  
May 21-25, 2012, 7 pages.

(Continued)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 279 days.

(21) Appl. No.: **13/897,254**

(22) Filed: **May 17, 2013**

(65) **Prior Publication Data**

US 2013/0310098 A1 Nov. 21, 2013

**Related U.S. Application Data**

(60) Provisional application No. 61/648,267, filed on May  
17, 2012.

(51) **Int. Cl.**  
**H04W 72/04** (2009.01)  
**H04W 24/00** (2009.01)  
**H04L 5/00** (2006.01)  
**H04W 24/02** (2009.01)

(52) **U.S. Cl.**  
CPC ..... **H04L 5/0032** (2013.01); **H04W 24/02**  
(2013.01); **H04W 72/042** (2013.01)

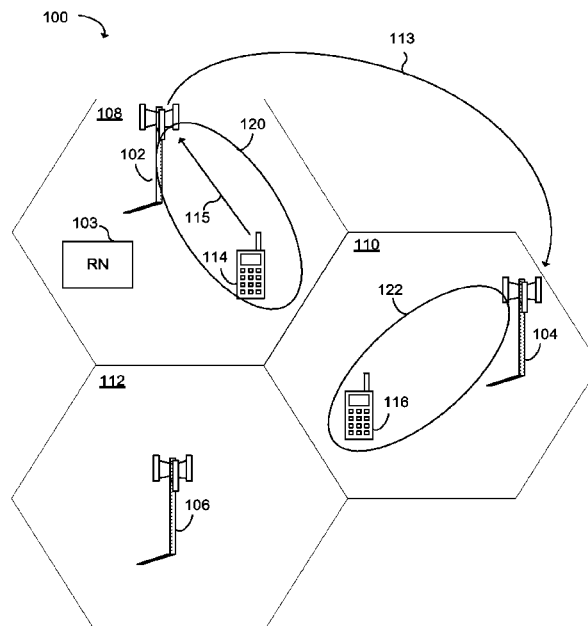
*Primary Examiner* — Philip Sobutka

(74) *Attorney, Agent, or Firm* — Slater & Matsil, L.L.P.

(57) **ABSTRACT**

A uniform feedback format mandates that mandates that DPS  
CSI, JT CSI, and CQI are reported irrespective of which  
transmission scheme was previously used to perform trans-  
missions. The DPS CSI, JT CSI, and CQI are then used to  
select a transmission scheme from a group of candidate trans-  
mission schemes. The selected transmission scheme can be a  
CoMP transmission scheme.

**17 Claims, 8 Drawing Sheets**



(56)

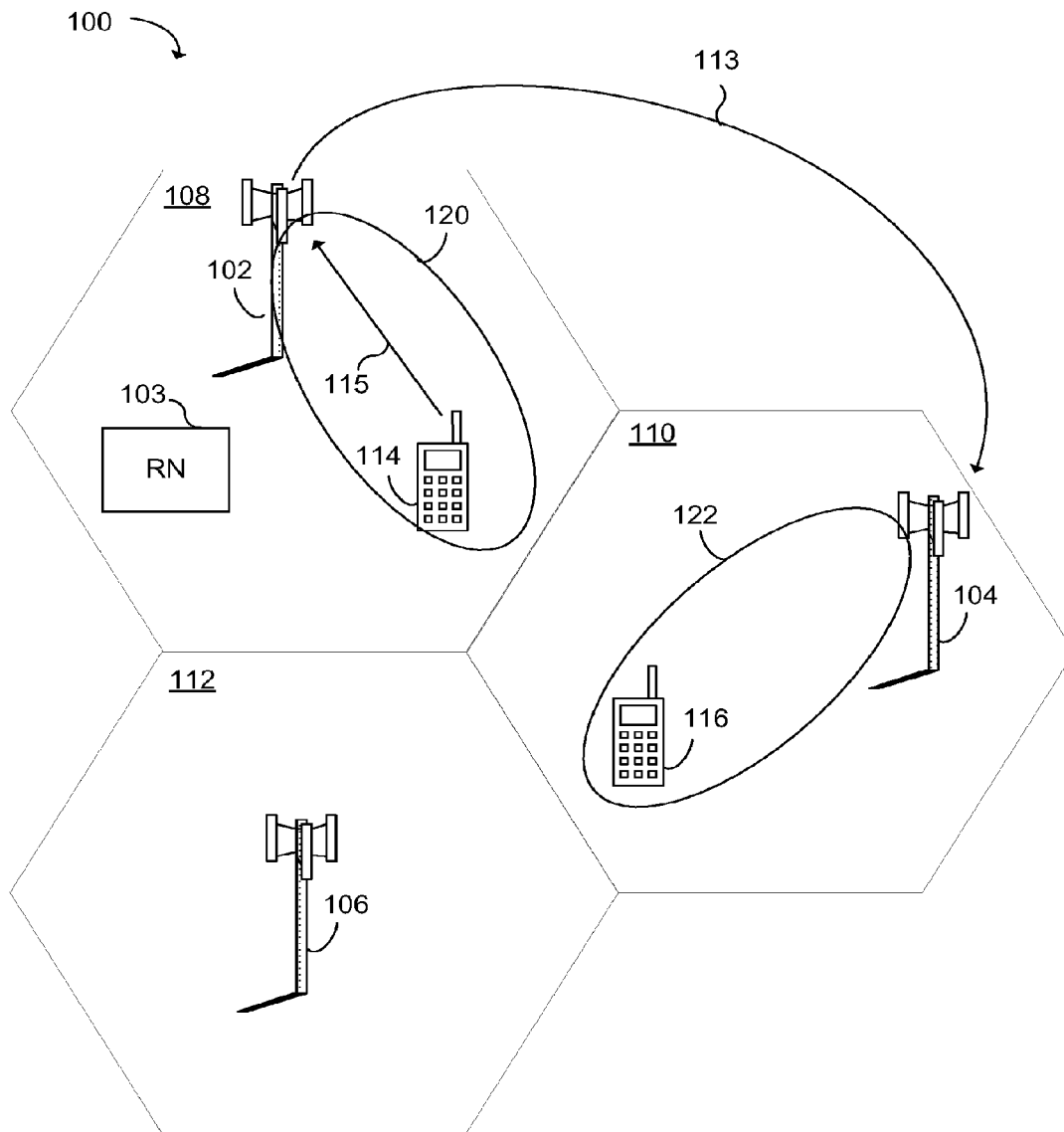
**References Cited**

OTHER PUBLICATIONS

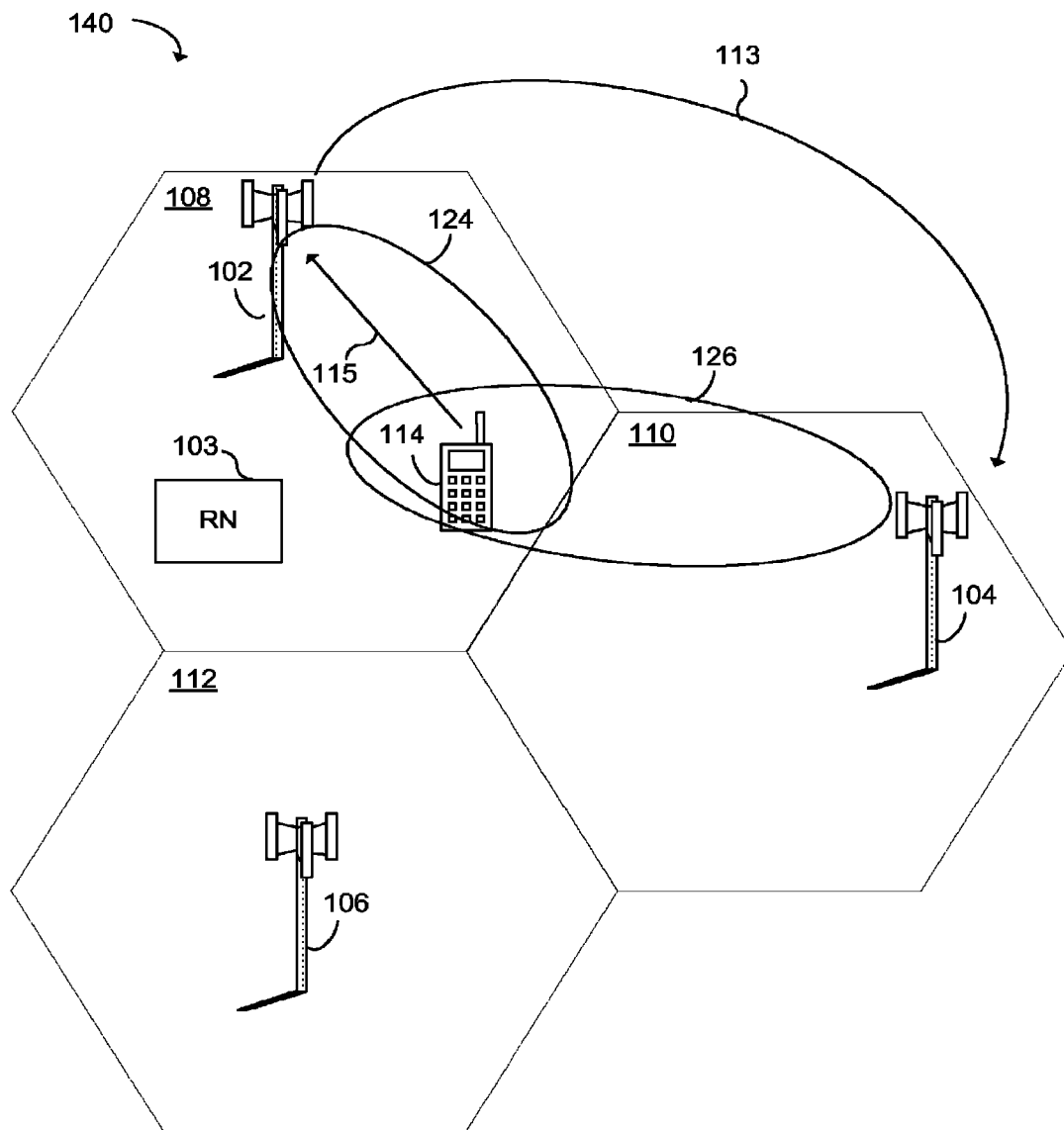
3<sup>rd</sup> Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (Release 8), 3GPP TS 36.212 v8.7.0, 60 pages, May 2009.

IEEE, "IEEE Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements; Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," IEEE Std 802.11™-2014, (Revision of IEEE Std 802.11-2007), Mar. 29, 2012, 2793 pages.

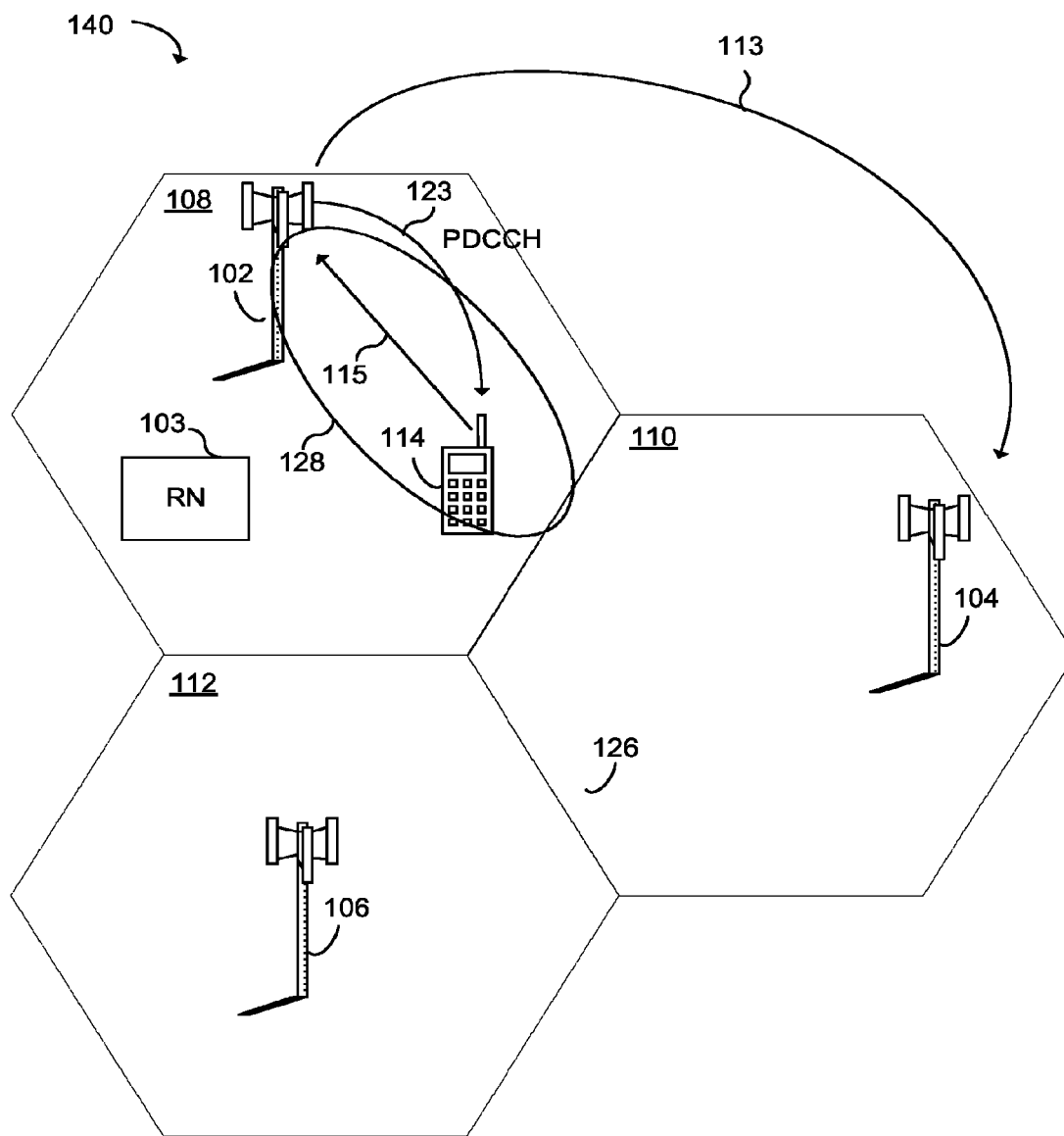
\* cited by examiner



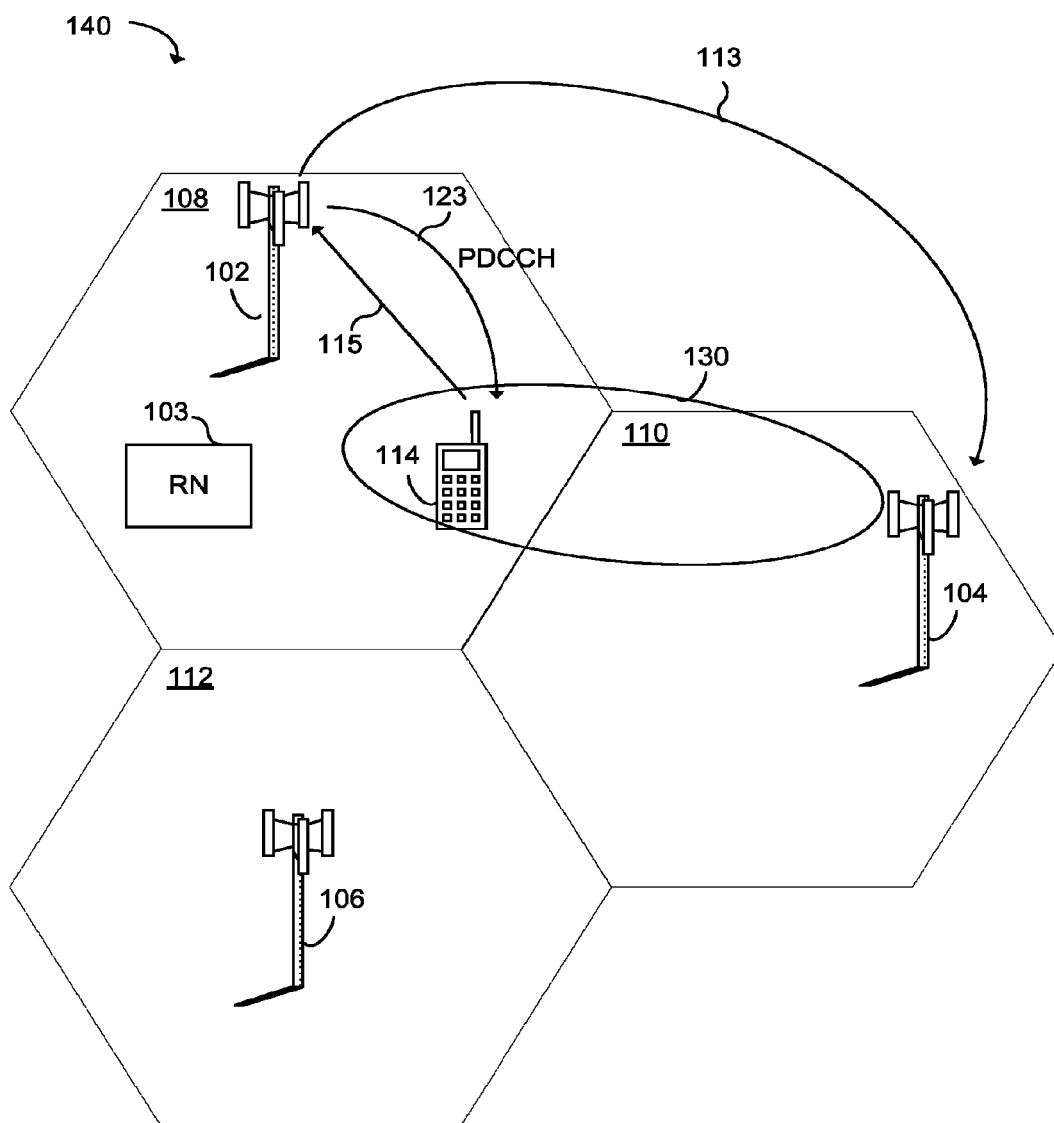
**Fig. 1**



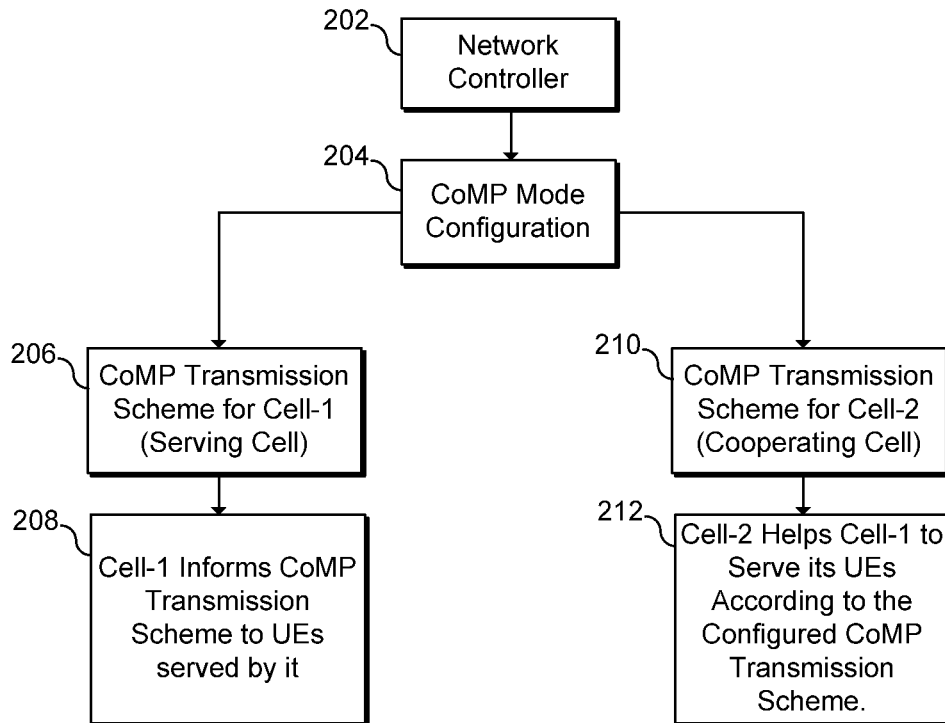
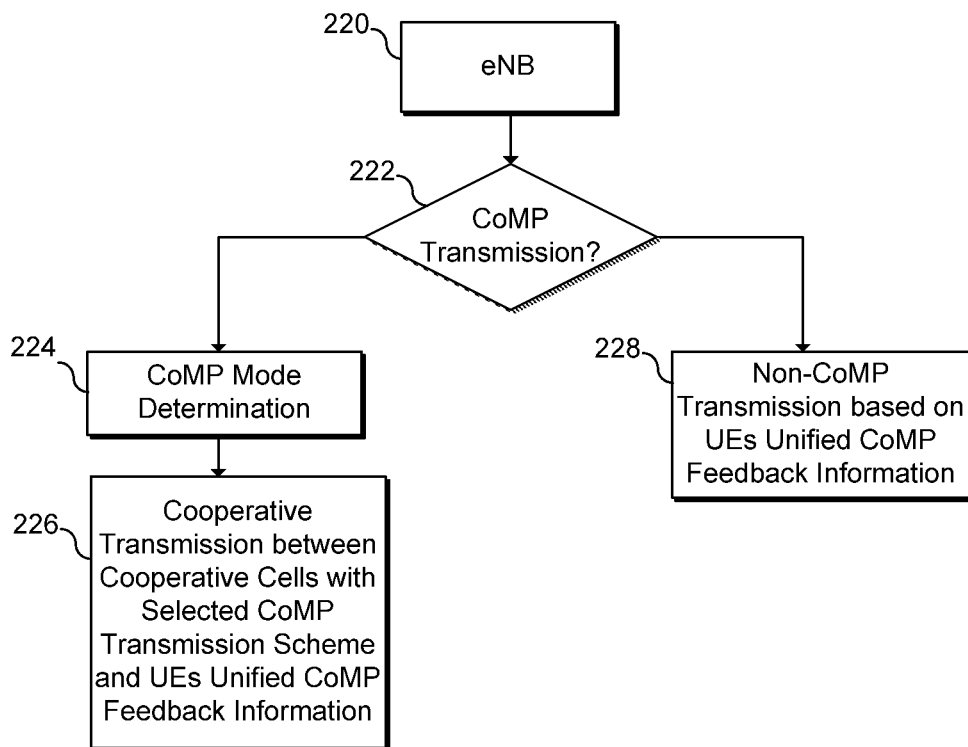
**Fig. 2**

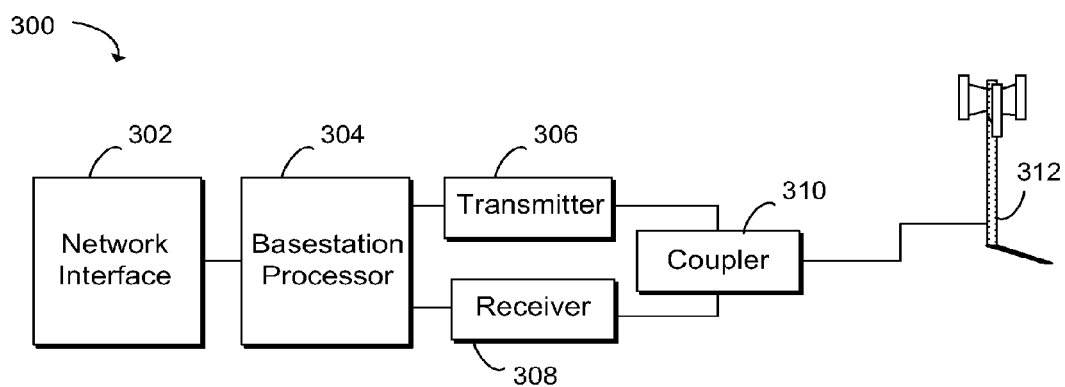
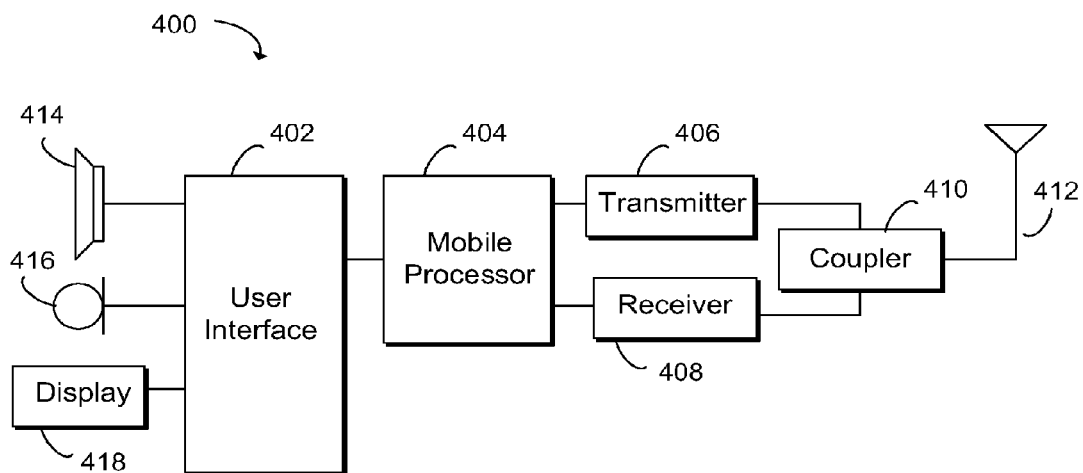


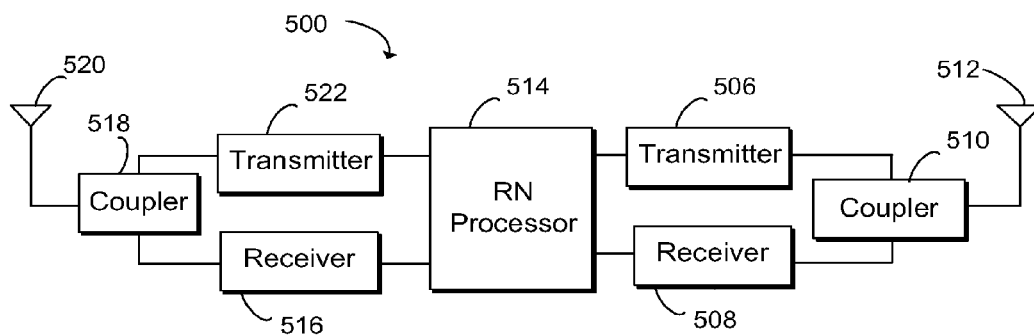
**Fig. 3a**



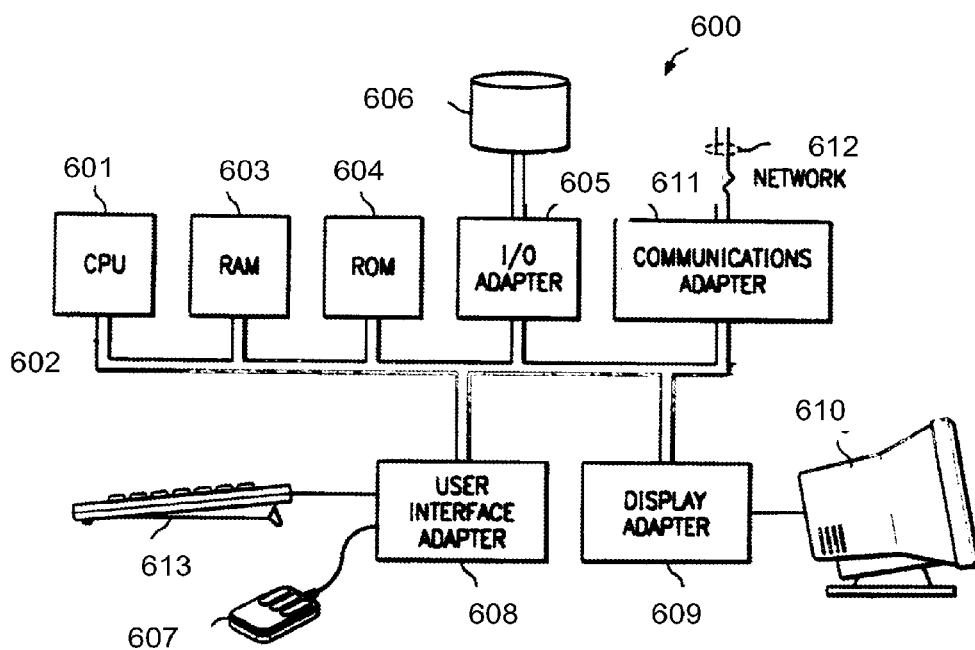
**Fig. 3b**

*Fig. 4**Fig. 5*

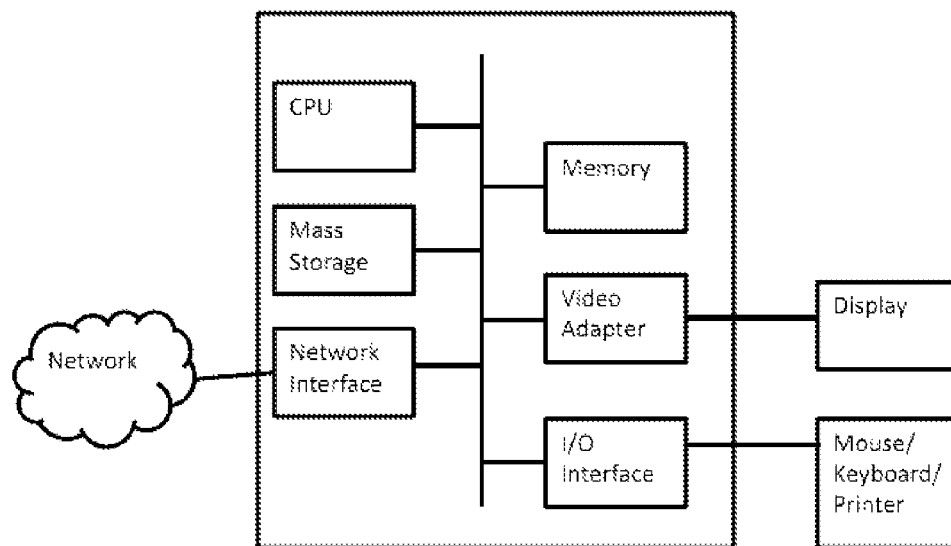
**Fig. 6****Fig. 7**



**Fig. 8**



**Fig. 9**

***Fig. 10***

1

## SYSTEM AND METHOD FOR ADAPTIVE DOWNLINK COMP MODE SELECTION BASED ON UNIFIED CSI FEEDBACK

This application claims the benefit of U.S. Provisional Application No. 61/648,267 filed on May 17, 2012, entitled “System and Method for adaptive downlink (DL) coordinated multipoint (CoMP) operation,” which is incorporated herein by reference as if reproduced in its entirety.

### TECHNICAL FIELD

The present invention relates to a system and method for wireless communications, and, in particular embodiments, to a system and method for adaptive downlink (DL) coordinated multipoint (CoMP) operation.

### BACKGROUND

Wireless communication systems are widely used to provide voice and data services for multiple users using a variety of access terminals such as cellular telephones, laptop computers and various multimedia devices. Such communication systems can encompass local area networks, such as IEEE 802.11 networks, cellular telephone and/or mobile broadband networks. The communication systems can use one or more multiple access techniques, such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Single Carrier Frequency Division Multiple Access (SC-FDMA) and others. Mobile broadband networks can conform to a number of system types or partnerships such as, General Packet Radio Service (GPRS), 3rd-Generation standards (3G), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications System (UMTS), the 3rd Generation Partnership Project (3GPP) including Long Term Evolution (LTE), IEEE 802.11 networks, and Evolution-Data Optimized (EV-DO).

In the downlink channel (DL) of a wireless communication system, coordinated multipoint (CoMP) transmission schemes are used to enhance coverage. By using multiple transmitters in a system, and choosing among the multiple transmitters or jointly broadcasting among the multiple transmitters, coverage can be expanded and data rates can be increased over systems that relay on a single transmitter. In order to implement CoMP schemes, however, user devices or user equipment (UE) typically need to provide more feedback to the base station. Different CoMP schemes are suitable for different deployment scenarios, and, therefore, generally have different feedback requirements.

Supporting these different feedback schemes can come at a cost of extra system overhead. For example, channel feedback can be used to support CoMP transmission, but generally requires a very high feedback overhead. Furthermore, multiple implicit feedback schemes for different DL CoMP transmission schemes can be used, but generally require multiple feedback formats, which, in turn, require more system resources to implement. In multiple feedback schemes, the transmission mode and feedback should follow each other, and there is a lack of flexibility at the scheduler. Multiple feedback schemes also generally would need multiple feedback mechanisms and channels in the standard, with different optimization criteria.

### SUMMARY

Technical advantages are generally achieved, by embodiments of this disclosure which describe a system and method for adaptive downlink (DL) coordinated multipoint (CoMP) operation.

2

In accordance with an embodiment, a method for adaptive coordinated multipoint (CoMP) mode selection is provided. In this example, the method includes receiving unified feedback information from a user equipment (UE) in accordance with a uniform feedback format. The unified feedback information comprises dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information. The method further includes selecting a transmission scheme in accordance with the unified feedback information; and sending a downlink transmission to the UE in accordance with the selected transmission scheme. An apparatus for performing this method is also provided.

In accordance with another embodiment, a method for facilitating adaptive coordinated multipoint (CoMP) mode selection is provided. In this example, the method includes sending unified feedback information to a base station in accordance with a uniform feedback format. The unified feedback information comprises dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information. The method further includes receiving a downlink transmission in accordance with a CoMP transmission scheme. The CoMP transmission scheme is selected in accordance with the unified feedback information. An apparatus for performing this method is also provided.

In accordance with yet another embodiment, another method for adaptive coordinated multipoint (CoMP) mode selection is provided. In this example, the method includes receiving signaling to enable unified feedback including dynamic point selection (DPS) and joint transmission (JT) channel state information (CSI) and channel quality information (CQI), selecting a dynamic serving transmit point, determining a precoding matrix indicator (PMI) and CQI for the dynamic serving transmit point, determining the PMI and CQI for one or more helping transmit points containing inter-transmit point information, and reporting the PMI and CQI for the dynamic serving transmit point and for the one or more helping transmit points.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates a diagram of an embodiment mobile broadband system operating in a coordinated beam forming (CBF) mode;

FIG. 2 illustrates a diagram of an embodiment mobile broadband system operating in a joint processing (JP) mode;

FIGS. 3a and 3b illustrate a diagrams of an embodiment mobile broadband system operating in a dynamic cell selection (DCS) mode;

FIG. 4 illustrates an embodiment CoMP mode configuration method;

FIG. 5 illustrates a further embodiment CoMP mode configuration method;

FIG. 6 illustrates an embodiment base station;

FIG. 7 illustrates an embodiment user device;

FIG. 8 illustrates an embodiment repeater node;

FIG. 9 illustrates an embodiment processing system used to implement embodiment algorithms; and

FIG. 10 illustrates a block diagram illustrating a computing platform that may be used for implementing, for example, the devices and methods described herein, in accordance with an embodiment.

Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the embodiments and are not necessarily drawn to scale.

#### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of embodiments of this disclosure are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

In a multi-point system, different transmission modes can be used with different feedback schemes. In U.S. Patent Application Publication No. 2011/0103287, entitled "System and Method for Unified Feedback in a Communication System," published on May 5, 2011, which is hereby incorporated herein by reference, precoders for different nodes are fed back. This enables different CoMP schemes: joint transmission (JT), coordinated beam forming (CBF) and dynamic point selection (DPS) (with or without muting), etc. DPS and JT generally are the most promising CoMP schemes and are beneficial in different scenarios. DPS generally is more beneficial when the short term signal strengths from different points are different from each other. JT generally is more beneficial when the signal strengths from different nodes are close.

##### Conventional Schemes

Disclosed herein are techniques for providing unified feedback information in accordance with a uniform feedback format. The uniform feedback format mandates that DPS CSI, JT CSI, and CQI are reported irrespective of which transmission scheme is selected prior to or subsequent to reporting the uniform feedback information. Upon receiving the uniform feedback information, a base station may select a transmission scheme from a group of candidate transmission schemes. The selected transmission scheme may be a CoMP transmission scheme.

A method for adaptive CoMP mode selection in a wireless communications system includes receiving, by a UE, signaling to enable unified feedback including DPS and JT CSI and CQI, selecting a dynamic serving transmit point, determining a precoding matrix indicator (PMI) and CQI for the dynamic serving transmit point, determining the PMI and CQI for one or more helping transmit points containing inter-transmit point information, and reporting the PMI and CQI for the dynamic serving transmit point and for the one or more helping transmit points.

In an embodiment, different mechanisms enable dynamic CoMP scheme adaptation. An embodiment provides adaptive selection of the transmission point by incorporating DPS in the feedback optimization. A UE measures and feeds back the information with multi-point. Such information encapsulates dynamic point selection and joint transmission channel state information (CSI) and channel quality indicator (CQI). An actual transmission scheme is selected by the network that may be different from the feedback. An embodiment provides adaptive transmission mode selection and combines DPS into the unified feedback. An embodiment provides signaling to enable/disable unified feedback, and signaling to enable/disable JT feedback or change the optimization criteria.

An embodiment provides simplification of feedback in the standard while improving the performance of unified feed-

back. An embodiment improves the performance of DPS using unified feedback, enabling adaptive transmission mode selection. An embodiment provides an LTE standard to select feedback scheme for enabling CoMP. An embodiment enables the standard to simplify feedback optimization and reduce UE complexity while maximizing the scheduling flexibility over transmission mode selection. An embodiment improves the performance on DPS, which in general is the simplest CoMP scheme. Embodiments may be applied to systems and devices, such as base stations and UEs implementing LTE, other standards, and proprietary solutions.

An adaptive CoMP mode embodiment dynamically switches between DPS and JT. The embodiment provides a unified UE feedback scheme for adaptive DPS/JT, high layer signaling to enable unified feedback, and CoMP mode selection determined by the network.

A unified UE feedback scheme for adaptive DPS/JT selects the dynamic serving transmit point. The embodiment selects precoding matrix indicator (PMI)/CQI sequentially by selecting PMI/CQI for a dynamic serving transmit point, and selecting PMI/CQI for helping transmit points. Alternatively, an embodiment jointly selects PMI/CQI for all transmit points including the serving transmit point. Having access to PMI/CQI from some modes, the CQI/PMI for other modes can be derived, however, all combinations may not be straight forward. A transmit point may be a base station transmitter in a cell or sector, one of the remote radio heads in a cell, a low-power Pico transmitter, a virtual transmit point that includes more than one base station transmitter, more than one remote radio head, more than one low power Pico transmitter, or any combination of base station transmitters, remote radio heads and low power Pico transmitters.

An embodiment provides high layer signaling to enable unified feedback. The network may use a demodulation reference signal (DMRS) and hide the selected operation mode or the actual transmission point for DPS and CBF. It may explicitly use signaling in the grant or radio resource control (RRC) signaling to identify the used transmit operation mode. The network can ask the UE (e.g., through RRC) to enable or disable the unified feedback scheme. For example, maybe only a high end terminal can support such features. The network can ask the UE (e.g., through RRC, or implicitly) to change the PMI/CQI optimization/evaluation method in case more than one is allowed by the standard.

With respect to feedback signaling, a UE may or may not explicitly report the selected dynamic transmit point identity. With reference signal received power (RSRP) reported by the UE, for example, in a first option described below, the higher CQI between 1 and 2 automatically shows which transmit point has higher short+long term signal power and hence the best selected point. For some other implementations, the selected transmit point can be reported wideband or subband and updated on every feedback or through less frequent updating compared to PMI or CQI.

In an embodiment the network selects the CoMP mode according to one or more of the following factors: UE feedback type (only a UE using unified feedback can be a candidate for DPS/JT adaptation), load balance, and UE-centric CoMP set optimization. Assuming DMRS is used, the actual transmission mode can be chosen transparent to the UE.

Examples of different implementations are provided below. The algorithms generally can work in JT-enabled or disabled modes. Without a loss of generality, assume  $K=2$  transmit points in the feedback CoMP set and precoding  $F_1$  and  $F_2$  feedback for channel matrices  $H_1$  and  $H_2$  where JT is  $H_1F_1 + H_2F_2$ . This can be extended to all other feedback varia-

tions. Also without a loss of generality, examples describe sequential PMI selection, but this can be extended to joint optimization.

A first option selects transmit point  $k$  in set  $\{1,2\}$  as the dynamic transmit point, reports  $PMI_k$  and  $CQI_k$  for transmit point  $k$  assuming the other transmit point is muted, and reports PMI for the other transmit point and CQI when transmit point  $k$  is muted, for a total up to  $K$  CQIs and  $K$  PMIs. If JT is enabled, CQI for JT can be estimated, and PMIs with or without any change can be used. For DPS with muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be used directly. For DPS without muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be estimated using feedback CQI levels. For CBF, CQI for CBF can be estimated, PMIs with or without any change can be used, and either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ .

A second option selects transmit point  $k$  in set  $\{1,2\}$  as the dynamic transmit point, reports  $PMI_k$  and  $CQI_k$  for transmit point  $k$  assuming the other transmit point is muted, and reports PMI for the other transmit point and CQI when this transmit point is helping transmit point  $k$  (CoMP CQI), for a total up to  $K$  CQIs and  $K$  PMIs. If JT is enabled, CQI for JT is available, and PMIs with or without any change can be used. For DPS with muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be used directly. For DPS without muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be estimated using feedback CQI levels. For CBF, CQI for CBF can be estimated, PMIs with or without any change can be used, and either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ .

A third option selects transmit point  $k$  in set  $\{1,2\}$  as the dynamic transmit point, reports  $PMI_k$  and  $CQI_k$  for transmit point  $k$  assuming the other transmit point is not muted, and reports PMI for the other transmit point and CQI when this transmit point is helping transmit point  $k$  (CoMP CQI), for a total up to  $K$  CQIs and  $K$  PMIs. If JT is enabled, CQI for JT is available, and PMIs with or without any change can be used. For DPS with muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be estimated using feedback CQI levels. For DPS without muting, either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ , and CQI can be used directly. For CBF, CQI for CBF can be estimated, PMIs with or without any change can be used, and either transmit point can be used as the dynamic serving transmit point, preferably transmit point  $k$ .

As an example of PMI/CQI derivation for the first option,  $CQI_1$  and  $CQI_2$  are both available assuming the other point is muted. For SU-JT, PMIs can be directly used, and  $CQI_{JT} = (CQI_1^{0.5} + CQI_2^{0.5})^2$ , where CQIs are in the linear domain. For DPS without muting, if transmit point 1 is selected as the current serving transmit point,  $CQI_1$  can be updated based on the estimated leakage from the cooperating transmit point and knowledge of  $CQI_2$ .  $CQI_{DPS} = CQI_1 / CQI_2$ , where CQIs are in the linear domain. For CBF, PMI for serving transmit point can directly be used, and PMI for the other transmit point needs to be avoided. If transmit point 1 is selected as the current serving transmit point,  $CQI_1$  can be updated based on the estimated leakage from the cooperating transmit point and knowledge of  $CQI_2$ .

In embodiments, a unified implicit feedback scheme for DL CoMP is applied to different DL CoMP modes, including

coordinated scheduling/beamforming, dynamic cell selection and coherent and non-coherent joint transmission. In some embodiments, the unified transmission scheme is further used in non-Comp transmission schemes. The unified implicit feedback scheme is also used in the context of a dynamic switch between different CoMP modes and between single-cell transition and CoMP transmission in further embodiments.

In an embodiment, the unified feedback format is an LTE rel-8 PMI based feedback format, which is used for DL CoMP transmission modes, a transparent DL transmission mode switch, and a hybrid DL CoMP implementation.

Compared with single site transmission, more feedback information is needed to enable CoMP modes, such as coordinated scheduling (CS), coordinated beam forming (CB), and joint transmission and dynamic cell selection (JP). Generally feedback falls into two categories: Implicit feedback and explicit feedback. Implicit feedback is based on the hypotheses of different transmission and/or reception processing. One example of implicit feedback is a precoding matrix indicator (PMI). In one embodiment, a user device or user equipment (UE) derives channel characteristics and selects a best precoder matrix from a list of precoder matrices. The PMI is a code taken from a code book that indicates the preferred precoder. Because only a code or index is sent, the UE does not have to transmit the entire channel information.

Explicit feedback, on the other hand, represents the channel as observed by the receiver without assuming transmission or receiver processing. Embodiments of the present invention use a PMI based implicit feedback scheme having a low feedback overhead that is backward compatible with the rel-8 LTE standard, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 8)," 3GPP TS 36.211 V8.7.0 (2009-05), which is incorporated herein by reference in its entirety. Furthermore, some embodiments use a uniform feedback channel format, such as PMI, for all CoMP modes. Some embodiments use a uniform feedback channel and differing amounts of feedback information within the feedback channel. For example transmission modes, such as coherent joint transmission (JT) require more feedback information than other modes, such as internal phase correction. Further discussion of CoMP communication techniques can be found in U.S. patent application Ser. No. 12/830,405 filed on Jul. 5, 2010, entitled "System and Method for Multi-Cell Joint Codebook Feedback in Wireless Communications Systems," while application is hereby incorporated herein by reference in its entirety. It should be appreciated that the uniform feedback format is not specifically limited to PMI feedback. In embodiments, the uniform feedback format can be a channel index, precoding index, or other representation that succinctly represent a channel. Furthermore, it should be appreciated that embodiments described herein are not limited to LTE systems, in that concepts of the described embodiments can be applied to non-LTE systems such as network systems having distributed antennas.

In one embodiment, a common PMI Feedback Format and overhead is used for Coordinated Beam Forming (CBF) and joint processing (JP). FIG. 1 illustrates a diagram of embodiment mobile broadband system 100 operating in a coordinated beam forming (CBF) mode. Mobile broadband system 100 has base station 102 in cell 108 that communicates with user device, mobile terminal or user equipment (UE) 114. Mobile broadband system 100 also has base station 104 in cell 110 that communicates with user device, mobile terminal or

UE 116 and base station 106 in cell 112. While three base stations 102, 104 and 106 and two UEs 114 and 116 are shown for simplicity of illustration, multiple cells, UEs can be used and provided for in real systems. In further embodiments, repeater node RN 103 can also be in communication with base stations 102, 104 and/or 106, as well as participate in CoMP mode transmissions with one or more UEs. In some embodiments, for example, embodiments that operate on an LTE network, base stations 102, 104 and 106 are implemented by an enhanced node B (eNB). In alternative embodiments, other systems besides LTE can be used, for example, a network system with distributed antennas.

In an embodiment CBF mode, cell 108 acts as a serving cell for UE 114 and a cooperating cell for UE 116, and cell 110 acts as a serving cell for 116 and as a cooperating cell for UE 114. Base station 102 communicates with UE 114 with signal 120. UE 114, in turn transmits preferred PMI feedback 115 back to base station 102 and companion PMI feedback 113 to base station 104 via base station 102. In an embodiment, the PMI feedback is communicated from UE 114 to base station 102, then from base station 102 to base station 104 via an X2 signaling interface. In one embodiment, preferred PMI is the index corresponding to a preferred precoder as determined, for example, by the UE. In an embodiment, the companion PMI can be a worst interfering PMI or best interfering PMI. In an embodiment, cooperating cells use the companion PMI to tell the coordinating base station in the cooperating cell, for example, a precoding direction that should be avoided. This information can also be used by the coordinating base station with respect to scheduling decisions. In an embodiment, the PMI is formatted according to rel-8 of the LTE standard with scalable feedback. For example, in a non-coherent JT mode, N PMIs are reported, where N is the number of cells involved in the CoMP transmission. For each PMI report, a rel-8 single cell PMI feedback channel is used in one embodiment. Alternatively, other PMI formats besides LTE rel-8, or other feedback formats.

FIG. 2 illustrates a diagram of embodiment mobile broadband system 140 operating in a joint processing (JP) mode. Here, both base station 102 of cell 108 and base station 104 of cell 110 communicate with UE 114 via signals 124 and 126, respectively. UE 114 transmits PMIs 115 to base station 102 and PMI 113 to base stations 104 via base station 102 using, for example, an X2 signaling interface. In further embodiments, other interfaces between the base stations can be used. In embodiments where the JP mode is a non-coherent joint transmission (JT) mode, UE 114 transmits preferred PMIs to

base station 102 and to base station 104 via base station 102. In embodiments, where the JT mode is a coherent transmission mode, the UE transmits two PMIs to each base station, namely a joint PMI for the combined channel and a PMI for coherent channel combining.

In one embodiment, the UE transmits the PMIs directly to the base station of the serving cell, and indirectly to the coordinating cell via the service base station using, for example, an X2 signaling interface. In one embodiment the PMI for coherent channel combining is derived according to:

$$G_{unified} = (H_1 + H_2 F_2^{(N_{T,L})}) Q^{(L)}$$

where  $H_1$  is the channel matrix of the serving cell,  $H_2$  is a channel matrix of the coordinating cell,  $F_2$  is a matrix selected from a codebook to constructively combine the channel  $H_1$  and  $H_2$ ,  $Q$  is a preferred PMI for the combined channel that is selected from a codebook,  $N_{T,L}$  is a number of transmit antennas from the coordinating cell, and  $L$  is the number of layers transmitted for the combined channel. In an embodiment,  $F_2$  is a combined matrix selected from the LTE rel-8 codebook and  $Q$  is a preferred PMI selected from the LTE rel-8 codebook. Table 1 describes the LTE rel-8 codebook for two antenna ports, and Table 2 describes the LTE rel-8 codebook for four antenna ports. The quantity  $W_n^{(s)}$  denotes the matrix defined by the columns given by the set  $\{s\}$  from the expression  $W_n = I - 2u_n u_n^H / u_n^H u_n$ , where  $I$  is the  $4 \times 4$  identity matrix and the vector  $u_n$  is given by Table 2. Alternatively, other codebooks according to other systems can be used.

TABLE 1

Codebook for transmission on antenna ports {0, 1}.		
Codebook	Number of layers v	
index	1	2
0	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
1	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
2	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$
3	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix}$	—

TABLE 2

Codebook for transmission on antenna ports {0, 1, 2, 3}					
Codebook		Number of layers v			
index	$u_n$	1	2	3	4
0	$u_0 = [1 \ -1 \ -1 \ -1]^T$	$W_0^{(1)}$	$W_0^{(14)}/\sqrt{2}$	$W_0^{(124)}/\sqrt{3}$	$W_0^{(1234)}/2$
1	$u_1 = [1 \ -j \ 1 \ j]^T$	$W_1^{(1)}$	$W_1^{(12)}/\sqrt{2}$	$W_1^{(123)}/\sqrt{3}$	$W_1^{(1234)}/2$
2	$u_2 = [1 \ 1 \ -1 \ 1]^T$	$W_2^{(1)}$	$W_2^{(12)}/\sqrt{2}$	$W_2^{(123)}/\sqrt{3}$	$W_2^{(13214)}/2$
3	$u_3 = [1 \ j \ 1 \ -j]^T$	$W_3^{(1)}$	$W_3^{(12)}/\sqrt{2}$	$W_3^{(123)}/\sqrt{3}$	$W_3^{(13214)}/2$
4	$u_4 = [1 \ (-1-j)/\sqrt{2} \ -j \ (1-j)/\sqrt{2}]^T$	$W_4^{(1)}$	$W_4^{(14)}/\sqrt{2}$	$W_4^{(124)}/\sqrt{3}$	$W_4^{(1234)}/2$
5	$u_5 = [1 \ (1-j)/\sqrt{2} \ j \ (-1-j)/\sqrt{2}]^T$	$W_5^{(1)}$	$W_5^{(14)}/\sqrt{2}$	$W_5^{(124)}/\sqrt{3}$	$W_5^{(1234)}/2$
6	$u_6 = [1 \ (1+j)/\sqrt{2} \ -j \ (-1+j)/\sqrt{2}]^T$	$W_6^{(1)}$	$W_6^{(13)}/\sqrt{2}$	$W_6^{(134)}/\sqrt{3}$	$W_6^{(1324)}/2$
7	$u_7 = [1 \ (-1+j)/\sqrt{2} \ j \ (1+j)/\sqrt{2}]^T$	$W_7^{(1)}$	$W_7^{(13)}/\sqrt{2}$	$W_7^{(134)}/\sqrt{3}$	$W_7^{(1324)}/2$
8	$u_8 = [1 \ -1 \ 1 \ 1]^T$	$W_8^{(1)}$	$W_8^{(12)}/\sqrt{2}$	$W_8^{(124)}/\sqrt{3}$	$W_8^{(1234)}/2$
9	$u_9 = [1 \ -j \ -1 \ -j]^T$	$W_9^{(1)}$	$W_9^{(14)}/\sqrt{2}$	$W_9^{(134)}/\sqrt{3}$	$W_9^{(1324)}/2$
10	$u_{10} = [1 \ 1 \ 1 \ -1]^T$	$W_{10}^{(1)}$	$W_{10}^{(13)}/\sqrt{2}$	$W_{10}^{(123)}/\sqrt{3}$	$W_{10}^{(1324)}/2$
11	$u_{11} = [1 \ j \ -1 \ j]^T$	$W_{11}^{(1)}$	$W_{11}^{(13)}/\sqrt{2}$	$W_{11}^{(134)}/\sqrt{3}$	$W_{11}^{(1324)}/2$
12	$u_{12} = [1 \ -1 \ -1 \ 1]^T$	$W_{12}^{(1)}$	$W_{12}^{(12)}/\sqrt{2}$	$W_{12}^{(123)}/\sqrt{3}$	$W_{12}^{(1234)}/2$
13	$u_{13} = [1 \ -1 \ 1 \ -1]^T$	$W_{13}^{(1)}$	$W_{13}^{(13)}/\sqrt{2}$	$W_{13}^{(123)}/\sqrt{3}$	$W_{13}^{(1324)}/2$

TABLE 2-continued

Codebook for transmission on antenna ports {0, 1, 2, 3}					
Codebook		Number of layers $v$			
index	$u_n$	1	2	3	4
14	$u_{14} = [1 \ 1 \ -1 \ -1]^T$	$W_{14}^{\{1\}}$	$W_{14}^{\{13\}/\sqrt{2}}$	$W_{14}^{\{123\}/\sqrt{3}}$	$W_{14}^{\{3214\}/2}$
15	$u_{15} = [1 \ 1 \ 1 \ 1]^T$	$W_{15}^{\{1\}}$	$W_{15}^{\{12\}/\sqrt{2}}$	$W_{15}^{\{123\}/\sqrt{3}}$	$W_{15}^{\{1234\}/2}$

In an embodiment, the PMI is formatted according to rel-8 of the LTE standard with a scalable feedback overhead. For example, in a non-coherent JT mode, N PMIs are reported, where N is the number of cells involved in the CoMP transmission. For each PMI report, a rel-8 single cell PMI feedback channel is used in one embodiment. Alternatively, other PMI formats, or other feedback formats, for example, additional interface information, can be used.

FIGS. 3a and 3b illustrate diagrams of embodiment mobile broadband system 140 operating in a dynamic cell selection (DCS) mode.

In a DCS embodiment, the UE transmits PMIs to both the serving cell and the cooperating cell and receives physical downlink control channel (PDCCH) from the serving cell. Transmission of the physical downlink shared channel (PDSCH), however, is switched between the serving cell and the cooperating cell depending on signal conditions and a selection algorithm. For example, in one embodiment, when the serving cell has a stronger signal, the serving cell is selected to transmit the PDSCH. On the other hand, when the cooperating cell has a stronger signal, the cooperating cell is selected to transmit the PDSCH.

FIGS. 3a and 3b illustrate diagrams of embodiment mobile broadband system 140 operating in a dynamic cell selection (DCS) mode. Here, UE 114 transmits PMI 115 to base station 102 in serving cell 108 and PMI 113 to base station 104 in cooperating cell 110. In the illustrated embodiment, UE 114 transmits PMI 113 to base station 102 of serving cell 108, which then sends PMI 113 to base station 104 of cooperating cell 110 via an interface, such as an X2 signaling interface. In further embodiments, other interfaces can be used. Base station 102 in serving cell transmits control information, for example, a PDCCH 128 to UE 114. In FIG. 3a, base station 102 of serving cell 108 transmits PDSCH 128 to UE 114. In one embodiment, base station 102 of serving cell 108 maintains the PDCCH with UE 114, while the PDSCH is changed between the serving cell and one or more cooperating cells. In FIG. 3b, base station 104 in cooperating cell 110 transmits PDSCH 130 to UE 114 and receives PDCCH 123 from base station 102 in serving cell 108.

In an embodiment, multi-user multiple-input multiple output (MU-MIMO) is applied together with DL CoMP. For example, MU-MIMO is combined with CBF and non-coherent JT CoMP schemes such that collaborating cells perform MU-MIMO pairing based on the companion PMIs. In one embodiment, reduced transmit power is used to minimize inter-user interference. In a further embodiment, the serving cell performs MU-MIMO pairing based on the preferred PMI.

In an embodiment, the transmit power of the serving cell and the coordinating cell to co-paired UEs can be reduced when MU-MIMO is implemented together with CBF. Here, the collaborated cells can perform MU-MIMO pairing considering companion PMIs and reduced transmit power can be used. Optionally, the serving cell can perform MU-MIMO pairing based on the preferred PMI, and may use the reduced transmit power.

In another embodiment, MU-MIMO is combined with coherent JT such that the serving cell determines the companion MU-MIMO PMI based on the reported joint PMI. Here, the collaborated cells determine the companion MU-MIMO PMI based on the reported joint PMI and channel combining PMI. In a further embodiment, MU-MIMO is combined with DCS such that the silent cell can serve other UE while taking into consideration the interference avoidance based on the PMI reported to the silent cell.

In an embodiment that uses a correlated antenna configuration, the base station applies DL covariance information to improve the unified feedback scheme based DL CoMP performance. In one embodiment, the DL covariance is obtained at the base station based uplink channel measurement feedback from a UE.

FIG. 4 illustrates a block diagram of CoMP Transmission Mode Switch. In an embodiment, a CoMP mode transmission switch is used to determine and switch between different CoMP and non-CoMP transmission modes. In one embodiment, the CoMP transmission mode switch is implemented by a processor in a base station or eNB. In other embodiments, the CoMP transmission switch can reside on a base station or a centralized controller.

In one embodiment network controller 202 configures CoMP mode configuration 204 using a semi-static adaptation based on operation scenarios such as, but not limited to, backhaul capability, traffic load, antenna configuration, delay sensitivity of the data to be transmitted and network loading. In some embodiments, the determined CoMP mode is broadcast to UEs directly via serving and/or cooperating cells. For example, the determined CoMP transmission scheme is set in serving cell (block 206), which then informs UEs served by the serving cell of the CoMP transmission mode (block 208). In an embodiment, the UEs are informed via system information blocks (SIB). Likewise, the determined CoMP transmission scheme is set in the cooperating cell (block 210) such that the cooperating cell assists the serving cell to serve the UEs according to the selected CoMP transmission scheme (block 212).

In a further embodiment, a CoMP slow mode adaptation is performed by using higher layer signaling to inform UE the change of the CoMP transmission mode. In one such embodiment, the UE understands the feedback mode based on the signaled CoMP mode. In one embodiment, the type of feedback that needs to be transmitted by the UE is predefined according to the CoMP transmission mode. Once the UE knows the CoMP transmission mode, the UE transmits the predefined feedback type.

In a further embodiment, a CoMP fast mode adaptation is performed such that the mode is transparent to the UE. In one embodiment, coherent JT feedback format is used as a baseline feedback scheme for all CoMP transmission modes. In such an embodiment, individual cell based PMIs, which are required by other CoMP modes, can be obtained by using the preferred PMI Q of the coherently combined channel for the serving cell PMI, and combined matrix FQ for the companion

11

PMI for the coordinating cell. In one embodiment, Q and FQ are used as defined in rel-8 of the LTE specification. For example, if the CoMP mode switch selects a CBF mode, the Q is used for the preferred PMI for the serving cell and FQ is used for the companion PMI in the coordinating cell. Using a fast CoMP mode adaptation, the system can switch between CoMP modes quickly without having to wait for CoMP transmission mode change information to propagate from the serving cell to all of the UEs.

FIG. 5 illustrates an embodiment fast CoMP mode adaptation method. In an embodiment, base station 220 determines whether a CoMP transmission is made according to a scheduling decision (block 222). In one embodiment, the base station 220 is an eNB. Alternatively, base station 220 can be another type of base station depending on the system and its specifications. If it is determined that CoMP transmission is being used, the particular CoMP mode is determined (block 224). In an embodiment, factors such as backhaul capability, traffic load, antenna configuration, delay sensitivity of the data to be transmitted and network loading are used to determine whether CoMP should be applied and to select the CoMP mode. Next, cooperative transmission between cooperative cells using the selected CoMP transmission mode is performed (block 226). In an embodiment, a unified feedback scheme, for example PMI feedback, is used for UE feedback. Alternatively, other unified feedback schemes can be used. If it is determined that a non-CoMP feedback scheme is being used, non-CoMP transmission is performed based on the UE's unified CoMP feedback information (block 228). For example, in one embodiment, Q is used as the precoder by the serving cell for non-CoMP transmission.

Advantages of embodiments using a CoMP switch include network flexibility, a mechanism to optimize overall system performance, a better trade off between cell capacity and cell coverage, and more scheduling flexibility to reduce the loss of the scheduling gain. Furthermore, with a unified feedback scheme, the dynamical CoMP mode switch becomes simpler to implement because, in some embodiments, scheduling can be optimized and there is no need to change the PMI feedback format. All that is changed, in an embodiment, is the PMI search approach. For example, in a non-CoMP mode, the preferred PMI is used for the serving cell, while in a CBF mode, the preferred PMI is used for the serving cell and the companion PMI is used for the cooperating cells. In a coherent JT mode, joint PMI is used, while in a non-coherent JT and fast cell selection mode, preferred PMIs are used for the serving cell and the cooperating cells.

In an embodiment, a communications system is operated using a mixed CBF and JP techniques, where CBF is used for inter-eNB CoMP and JP is used for intra-eNB CoMP. For the intra-eNB cells, JP feedback is used, and for inter-eNB cells, CBF feedback is used. In one embodiment, intra-eNB cells are distinguished from inter-eNB cells using an implicit method based on UE measurement. For example, a cell with no timing offset and a low inter-cell phase change rate can be considered as a cell from the same eNB. In a further embodiment, intra-eNB cells are distinguished from inter-eNB cells using an implicit method based on the cell ID and on cell group planning. For example, two cells belonging to the same group but having different cell IDs would have the same group ID but different cell IDs. In a yet a further embodiment, intra-eNB cells are distinguished from inter-eNB cells using an explicit method based on signaling. Here, the network broadcasts the cell ID information.

Advantages of using an embodiment mixed CBF/JP transmission scheme include the ability to optimize DL CoMP performance for system without having a fast high capacity

12

backhaul and the ability to simplify the coordination transmission between cooperative cells. For example, a fast, high capacity backhaul may not be available between eNBs in order to enable a JP mode between eNBs, however, JP between cells of the same eNB may be more practical in some embodiments.

A block diagram of an embodiment base station 300 is illustrated in FIG. 6. Base station 300 has base station processor 304 coupled to transmitter 306 and receiver 308, and network interface 302. Transmitter 306 and receiver 308 are coupled to antenna 312 via coupler 310. Base station processor 304 executes embodiment methods and algorithms. For example, Base station processor 304 can implement a CoMP mode switch, receive feedback from UEs using a uniform feedback format, and implement mixed mode CoMP transmission schemes in some embodiments. In an embodiment, base station 300 is configured to operate in a LTE network using an OFDMA downlink channel divided into multiple subbands and using single carrier FDMA in the uplink. In alternative embodiments, other systems, network types and transmission schemes can be used, for example, 1xEV-DO, IEEE 802.11, IEEE 802.15 and IEEE 802.16. In alternative embodiments, base station 300 can have multiple transmitters, receivers and antennas (not shown) to support MIMO operation.

A block diagram of embodiment user device or UE 400 is illustrated in FIG. 7. User device 400 can be, for example, a cellular telephone or other mobile communication device, such as a computer or network enabled peripheral. Alternatively, user device 400 can be a non-mobile device, such as a desktop computer with wireless network connectivity. User device 400 has mobile processor 404, transmitter 406 and receiver 408, which are coupled to antenna 412 via coupler 410. User interface 402 is coupled to mobile processor 404 and provides interfaces to loudspeaker 414, microphone 416 and display 418, for example. Alternatively, user device 400 may have a different configuration with respect to user interface 402, or user interface 402 may be omitted entirely. In embodiment, user device 400 is configured to operate according to embodiment algorithms. For example, user device can be configured to transmits feedback according to a uniform format, such as PMI, and operate according to various CoMP and non-CoMP transmission schemes. In alternative embodiments, user device 400 can have multiple transmitters, receivers and antennas (not shown) to support MIMO operation.

A block diagram of an embodiment relay node 500 is shown in FIG. 8. Relay node 500 has donor antenna 520, which transmits to and from the base station and is coupled to coupler 518, transmitter 522 and receiver 516. Service antenna 512, which transmits to and receives signals from user devices is coupled to coupler 510, transmitter 506 and receiver 508. RN processor 514, which is coupled to both the donor and service signal paths, controls the operation of relay node and implements embodiment algorithms described herein. For example, RN 400 can work with eNB 300 (FIG. 6) to implement CoMP transmission modes, receive UE feedback in a uniform format, and implement mixed mode CoMP transmission schemes in some embodiments. In an embodiment of the present invention, relay node 500 is configured to operate in a LTE network using an OFDMA downlink channel divided into multiple subbands and using single carrier FDMA in the uplink. In alternative embodiments, other systems, network types and transmission schemes can be used.

FIG. 9 illustrates computer system 600 adapted to use embodiments of the present invention, e.g., storing and/or executing software associated with the embodiments. Central processing unit (CPU) 601 is coupled to system bus 602. CPU

13

601 may be any general purpose CPU. However, embodiments of the present invention are not restricted by the architecture of CPU 601 as long as CPU 601 supports the inventive operations as described herein. Bus 602 is coupled to random access memory (RAM) 603, which may be SRAM, DRAM, or SDRAM. ROM 704 is also coupled to bus 602, which may be PROM, EPROM, or EEPROM. RAM 603 and ROM 604 hold user and system data and programs as is well known in the art.

Bus 602 is also coupled to input/output (I/O) adapter 605, communications adapter 611, user interface 608, and display adaptor 609. The I/O adapter 605 connects storage devices 606, such as one or more of a hard drive, a CD drive, a floppy disk drive, a tape drive, to computer system 600. Communications adapter 611 is configured to interface with network 612. The I/O adapter 605 is also connected to a printer (not shown), which would allow the system to print paper copies of information such as documents, photographs, articles, and the like. Note that the printer may be a printer, e.g., dot matrix, laser, and the like, a fax machine, scanner, or a copier machine. User interface adaptor is coupled to keyboard 613 and mouse 607, as well as other devices. Display adapter, which can be a display card in some embodiments, is connected to display device 610. Display device 610 can be a CRT, flat panel display, or other type of display device.

In an embodiment, a method of operating a communication device includes determining a first coordinated multipoint (CoMP) mode, electronically receiving feedback from a user device in the uniform feedback format, and determining transmission parameters of the first CoMP mode. The first CoMP mode includes one of a plurality of CoMP modes, and each of the plurality of CoMP modes is configured to operate using a uniform feedback format.

In an embodiment, the uniform feedback format comprises a precoder matrix indicator (PMI) feedback format. In a further embodiment, the method further includes determining a non-CoMP mode, and electronically receiving feedback parameters from the user device in the uniform feedback format while operating in the non-CoMP mode.

In an embodiment, the first CoMP mode is a non-coherent joint transmission (JT) mode based on the determining the transmission parameters. The communication device supports a serving cell or a cooperating cell, the PMI feedback includes a preferred PMI, and the method further includes computing a precoder based on the feedback from the user device, precoding a transmission with the precoder, and transmitting the precoded transmission to the user device. In one embodiment, the communication device supports a serving cell or a cooperating cell. In a further embodiment, the communication device further applies a multi-user multi-input-multi-output (MU-MIMO) transmission scheme based on the feedback from the user device.

In a further embodiment, the method includes transmitting a command to the user device to broadcast feedback content according to a joint transmission (JT) scheme as a baseline feedback scheme, whereby the determined first CoMP mode is transparent to the user device. In another embodiment, the method includes using high layer signaling to inform the user device of the determined first CoMP mode.

In a further embodiment, the first CoMP mode is a coherent joint transmission (JT) mode based on determining the CoMP transmission mode. The communication device supports a serving cell or a cooperating cell, the PMI feedback comprises a joint PMI for a combined channel, and the method further includes computing a precoder based on the feedback from the user device, precoding a transmission with the precoder, and transmitting the precoded transmission to the user

14

device. In one embodiment, the communication device further applies a multi-user multi-input-multi-output (MU-MIMO) transmission scheme based on the feedback from the user device, the communication device comprises a base station supporting a serving cell, the method further includes determining companion MU-MIMO PMI based on a reported joint PMI. In a further embodiment, the communications device comprises a base station supporting a collaborated cell, and the method further includes determining companion MU-MIMO PMI based on a reported joint PMI and based on a channel combining PMI.

In a further embodiment, the first CoMP mode is a coordinated beam forming (CBF) mode. In one embodiment, the communication device is a base station supporting a serving cell, the PMI feedback includes a preferred PMI, and the method further includes if it is determined that the serving cell is to transmit to the user device, computing a precoder based on the PMI feedback, precoding a transmission with the precoder, and transmitting the precoded transmission to the user device. Alternatively, communication device includes a base station supporting a cooperating cell communicating with a first user device, where the PMI feedback includes a companion PMI. In a further embodiment, the communication device further applies a multi-user multi-input-multi-output (MU-MIMO) transmission scheme based on the feedback from the user device.

In a further embodiment, the communication device further comprises a base station supporting a serving cell communicating with a second user device the method further comprises communicating with the second user device in a joint processing mode, communicating further comprising receiving PMI feedback from the second user device.

In an embodiment, the first CoMP mode is a dynamic cell selection mode (DCS) mode based on the determining. In one embodiment, the communication device further applies a multi-user multi-input-multi-output (MU-MIMO) transmission scheme based on the feedback from the user device. In a further embodiment, communication device supports a silent cell using the feedback from the user device to implement interference avoidance when transmitting to other user device. In a further embodiment, the communication device comprises a base station supporting serving cell, the PMI feedback comprises a preferred PMI, and the method further comprises, if it is determined that the serving cell is to transmit to the user device, computing a precoder based on the PMI feedback, precoding a transmission with the precoder, and transmitting the precoded transmission to the user device. Alternatively, the communication device comprises a base station supporting a cooperating cell and the PMI feedback comprises a companion PMI.

In an embodiment, the feedback received from the user device in the first CoMP mode comprises different content from feedback received from the user device in a second CoMP mode. The second CoMP mode comprises a further one of the plurality of CoMP modes, and the feedback received from the user device in the second CoMP mode includes the uniform feedback format.

In an embodiment, a communications device includes a transmitter, a receiver receiving feedback from a user device in a uniform feedback format, and a processor configured to determine a first transmission mode from a plurality of transmission modes, and determine transmission parameters of the first transmission mode based on the feedback. The first transmission mode comprises one of a plurality of transmission modes, and each of the plurality of transmission modes is configured to operate using the uniform feedback format. In an embodiment, the plurality of transmission modes com-

prises a plurality of coordinated multipoint (CoMP) modes. In a further embodiment, the plurality of transmission modes further comprises at least one non-CoMP transmission mode.

In a number of embodiments, the uniform feedback format comprises a precoder matrix indicator (PMI) feedback format. For example, in one embodiment, one of the plurality of CoMP modes includes at least one of a coherent joint transmission (JT) mode, a non-coherent joint transmission (JT) mode, a coordinated beam forming (CBF) mode, and a dynamic cell selection (DCS) mode. In one embodiment, the communication device applies a multi-user multi-input-multi-output (MU-MIMO) transmission scheme based on the feedback from the user device. In an embodiment, the processor determines the CoMP mode based on operation scenarios. In one embodiment, the communications device broadcasts operation mode to at least one user device. In a further embodiment, the communication device transmits a command to the user device to broadcast feedback content according to a joint transmission (JT) scheme as a baseline feedback scheme, whereby the determined first transmission mode is transparent to the user device.

In an embodiment, a communication device includes a receiver, a transmitter, and a processor coupled to the receiver and the transmitter. The processor is configured to operate the communication device in one of a plurality of operating modes, where the operating modes include a plurality of coordinated multipoint (CoMP) modes. In an embodiment, the processor is configured to generate a uniform feedback format for each of the CoMP modes. In a further embodiment, the plurality of CoMP operating modes includes at least one of a coherent joint transmission (JT) mode, a non-coherent joint transmission (JT) mode, a coordinated beam forming (CBF) mode, and a dynamic cell selection mode (DCS) mode. In an embodiment, the uniform feedback format comprises a precoder matrix indicator (PMI) feedback format. Also, in one embodiment, the communication device is further configured to operate in a non-CoMP mode using the uniform feedback format. In an embodiment, the processor generates different feedback in each of at least two of the plurality of operating modes.

In an embodiment, a method of operating a communication device includes operating the communication device in one of a plurality of operating modes, where the operating modes include a plurality of coordinated multipoint (CoMP) modes. The method further includes generating feedback using a uniform feedback format for each of the CoMP modes and transmitting the feedback to a user device at a transmitter. The uniform feedback format includes a precoder matrix indicator (PMI) feedback format. In one embodiment, the plurality of CoMP operating modes includes at least one of a coherent joint transmission (JT) mode, a non-coherent joint transmission (JT) mode, a coordinated beam forming (CBF) mode, and a dynamic cell selection mode (DCS) mode. In an embodiment, generating feedback includes generating different feedback in at least two of the plurality of operating modes. In one embodiment, the method further includes operating the communication device in a non-CoMP mode using the uniform feedback format.

In an embodiment, a method of operating a coordinated multipoint (CoMP) switch includes selecting a transmission mode. The transmission mode includes one of a plurality of transmission modes, and the plurality of transmission modes includes a plurality of coordinated multipoint (CoMP) modes. Each of the plurality of CoMP modes is configured to operate using a uniform feedback format, where the uniform format comprising a precoder matrix indicator (PMI) feedback format. In an embodiment, the method further includes

electronically receiving feedback from user devices in the PMI feedback format. In one embodiment, the plurality of transmission modes comprises a non-CoMP transmission mode.

In an embodiment, the a method of operating a CoMP switch further includes performing a semi-static mode adaptation that includes selecting the transmission mode based on operation scenarios, and broadcasting the operation mode to at least one user device. In a further embodiment, the method includes performing a slow mode adaptation, performing slow mode adaptation that includes using higher layer signaling to inform at least one user device of the transmission mode. In yet a further embodiment, a fast mode adaptation is performed where the mode adaptation is transparent to the at least one user device. In an embodiment, JT coherent feedback is used as a baseline feedback scheme when coherent JT is supported by the system. In an embodiment, the plurality of CoMP transmission modes comprise at least one of a coherent joint transmission (JT) mode, a non-coherent joint transmission (JT) mode, a coordinated beam forming (CBF) mode and a dynamic cell selection mode (DCS) mode. In further embodiments, other modes can be used.

In an embodiment, a coordinated multipoint (CoMP) switch includes a transmission mode selector that selects one of a plurality of transmission modes, where the plurality of transmission modes includes a plurality of coordinated multipoint (CoMP) modes. Each of the plurality of CoMP modes is configured to operate using a uniform feedback format, where the uniform format includes a precoder matrix indicator (PMI) feedback format. The CoMP switch also includes a receiver for receiving feedback from user devices in the PMI feedback format. In one embodiment, the plurality of transmission modes includes a non-CoMP transmission mode. In a further embodiment, the plurality of CoMP transmission modes comprise a coherent joint transmission (JT) mode, a non-coherent joint transmission (JT) mode, a coordinated beam forming (CBF) mode, and a dynamic cell selection mode (DCS) mode. Alternatively, other CoMP and non-CoMP modes can be used.

Although present embodiments and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. For example, many of the features and functions discussed above can be implemented in software, hardware, or firmware, or a combination thereof.

Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

FIG. 10 is a block diagram of a processing system that may be used for implementing the devices and methods disclosed herein. Specific devices may utilize all of the components shown, or only a subset of the components, and levels of integration may vary from device to device. Furthermore, a device may contain multiple instances of a component, such as multiple processing units, processors, memories, transmit-

17

ters, receivers, etc. The processing system may comprise a processing unit equipped with one or more input/output devices, such as a speaker, microphone, mouse, touchscreen, keypad, keyboard, printer, display, and the like. The processing unit may include a central processing unit (CPU), memory, a mass storage device, a video adapter, and an I/O interface connected to a bus.

The bus may be one or more of any type of several bus architectures including a memory bus or memory controller, a peripheral bus, video bus, or the like. The CPU may comprise any type of electronic data processor. The memory may comprise any type of system memory such as static random access memory (SRAM), dynamic random access memory (DRAM), synchronous DRAM (SDRAM), read-only memory (ROM), a combination thereof, or the like. In an embodiment, the memory may include ROM for use at boot-up, and DRAM for program and data storage for use while executing programs.

The mass storage device may comprise any type of storage device configured to store data, programs, and other information and to make the data, programs, and other information accessible via the bus. The mass storage device may comprise, for example, one or more of a solid state drive, hard disk drive, a magnetic disk drive, an optical disk drive, or the like.

The video adapter and the I/O interface provide interfaces to couple external input and output devices to the processing unit. As illustrated, examples of input and output devices include the display coupled to the video adapter and the mouse/keyboard/printer coupled to the I/O interface. Other devices may be coupled to the processing unit, and additional or fewer interface cards may be utilized. For example, a serial interface such as Universal Serial Bus (USB) (not shown) may be used to provide an interface for a printer.

The processing unit also includes one or more network interfaces, which may comprise wired links, such as an Ethernet cable or the like, and/or wireless links to access nodes or different networks. The network interface allows the processing unit to communicate with remote units via the networks. For example, the network interface may provide wireless communication via one or more transmitters/transmit antennas and one or more receivers/receive antennas. In an embodiment, the processing unit is coupled to a local-area network or a wide-area network for data processing and communications with remote devices, such as other processing units, the Internet, remote storage facilities, or the like.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A method for adaptive coordinated multipoint (CoMP) mode selection in a wireless communications system, the method comprising:

establishing a feedback channel;

receiving unified feedback information from a user equipment (UE) over the feedback channel, the unified feedback information being communicated in accordance with a uniform feedback format mandating that the unified feedback information includes dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information;

selecting a transmission scheme in accordance with the unified feedback information;

18

sending a downlink transmission to the UE in accordance with the selected transmission scheme; and  
receiving additional unified feedback information from the UE in accordance with the uniform feedback format, wherein the uniform feedback format mandates that the additional unified feedback information includes each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information irrespective of which transmission scheme is used to perform the downlink transmission.

2. The method of claim 1, wherein selecting the transmission scheme in accordance with the unified feedback information comprises:

selecting a dynamic point selection transmission scheme or a joint transmission scheme in accordance with the unified feedback.

3. The method of claim 1, wherein the transmission scheme is selected by a base station.

4. The method of claim 1, wherein the unified feedback format requires that each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

5. An apparatus comprising:

a processor; and

a non-transitory computer readable storage medium storing programming for execution by the processor, the programming including instructions to:

establish a feedback channel;

receive unified feedback information from the UE in accordance with a uniform feedback format mandating that the unified feedback information includes dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information;

select a transmission scheme in accordance with the unified feedback information;

send a downlink transmission to the UE in accordance with the selected transmission scheme; and

receive additional unified feedback information from the UE in accordance with the uniform feedback format, wherein the uniform feedback format mandates that the additional unified feedback information includes each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information irrespective of which transmission scheme is used to perform the downlink transmission.

6. The apparatus of claim 5, wherein the instructions to select the transmission scheme in accordance with the unified feedback information include instructions to:

select a dynamic point selection transmission scheme or a joint transmission scheme in accordance with the unified feedback.

7. The apparatus of claim 5, wherein the unified feedback format requires that each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

8. A method for facilitating adaptive coordinated multipoint (CoMP) mode selection in a wireless communications system, the method comprising:

receiving, by a user equipment (UE), a first downlink transmission;

performing channel estimation to generate unified feedback information in accordance with a uniform feedback format, wherein the unified feedback information mandates that the unified feedback information includes

19

dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information irrespective of which transmission scheme was used to communicate the first downlink transmission; sending the unified feedback information to a base station; receiving a second downlink transmission in accordance with a CoMP transmission scheme, the CoMP transmission scheme being selected in accordance with the unified feedback information; and sending additional unified feedback information to the base station in accordance with the uniform feedback format after receiving the second downlink transmission, wherein the uniform feedback format mandates that the additional unified feedback information includes each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information irrespective of which transmission scheme is used for the second downlink transmission.

9. The method of claim 8, wherein the CoMP transmission scheme comprises a dynamic point selection transmission scheme or a joint transmission scheme.

10. The method of claim 8, wherein the unified feedback format requires that each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

11. An apparatus comprising:

a processor; and

a non-transitory computer readable storage medium storing programming for execution by the processor, the programming including instructions to: receiving a first downlink transmission; performing channel estimation to generate unified feedback information;

send the unified feedback information to a base station in accordance with a uniform feedback format, wherein the unified feedback format mandates that the unified feedback information includes dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information irrespective of which transmission scheme was used to communicate the first downlink transmission;

receive a second downlink transmission in accordance with a CoMP transmission scheme, the CoMP transmission scheme being selected in accordance with the unified feedback information; and

send additional unified feedback information to the base station in accordance with the uniform feedback format after receiving the second downlink transmission, wherein the uniform feedback format mandates that the additional unified feedback information includes each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information irrespective of which transmission scheme is used for the second downlink transmission.

12. The apparatus of claim 11, wherein the CoMP transmission scheme comprises a dynamic point selection transmission scheme or a joint transmission scheme.

13. The apparatus of claim 11, wherein the unified feedback format requires that each of the dynamic point selection

20

CSI, the joint transmission CSI, and the channel quality information be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

14. A method for adaptive coordinated multipoint (CoMP) mode selection in a wireless communications system, the method comprising:

receiving, by a user equipment (UE), signaling to enable a unified feedback mode that mandates the reporting of each of dynamic point selection (DPS) channel state information (CSI), joint transmission (JT) CSI, and channel quality information (CQI) irrespective of which transmission mode is used;

selecting, by the UE, a dynamic serving transmit point;

determining a precoding matrix indicator (PMI) and CQI for the dynamic serving transmit point;

determining the PMI and CQI for one or more helping transmit points containing inter-transmit point information;

reporting, by the UE, the PMI and CQI for the dynamic serving transmit point and for the one or more helping transmit points; and

reporting the DPS CSI, the JT CSI, and the CQI in accordance with the unified feedback mode.

15. The method of claim 14, wherein the unified feedback mode requires that each of the DPS CSI, the JT CSI, and the CQI be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

16. A method for fast coordinated multipoint (CoMP) mode adaptation, the method comprising:

activating a unified feedback mode of a user equipment (UE);

receiving unified feedback information from the UE in accordance with the unified feedback mode;

switching from a first transmission mode to a second transmission mode without notifying the UE;

performing downlink transmissions in accordance with the second transmission mode; and

continuing to receive unified feedback information from the UE after switching to the second transmission mode, wherein the unified feedback mode requires the UE to report the same number and type of feedback parameters irrespective of which transmission scheme is being used to communicate downlink transmissions, wherein the unified feedback mode requires the UE to report, as part of the unified feedback information, dynamic point selection channel state information (CSI), joint transmission CSI, and channel quality information irrespective of which transmission scheme is being used to perform the downlink transmissions.

17. The method of claim 16, wherein the unified feedback mode requires that each of the dynamic point selection CSI, the joint transmission CSI, and the channel quality information be reported for both a dynamic point selection transmission scheme and a joint transmission scheme.

\* \* \* \* \*